

Challenges to Crop Pests and Livestock Diseases Management in Irrigated African Agroecosystems under a Changing Climate

Fahim M. A. *¹; Hassanein M. K.¹; Abolmaty S. M.¹ and Fargalla F. H.²

¹ Central Laboratory for Agricultural Climate, P.O. Box 296 Dokki, 12411 Giza, Egypt

² Plant Protection Research Institute, Dokki, 12411 Giza, Egypt

ali.mohamed73@gmail.com

Abstract: Climate change creates new ecological niches, potentially allowing for the establishment and spread of plant pests and diseases to new geographical areas and from one region to another. Accordingly, it might also result in the emergence of new plant diseases and pests. Furthermore, changes in species composition might augment the occurrence of unexpected events, including the emergence of new diseases and pests. These additional opportunities for entry, establishment and spread might generally result in higher uncertainty. In Africa, the best economic strategy for farmers is to use integrated pest management practices to closely monitor insect and disease occurrence. Keeping pest and crop management records over time will allow farmers to evaluate the economics and environmental impact of pest control and determine the feasibility of using certain pest management strategies or growing particular crops. In view of the large number of plant/livestock diseases and pests, it is clear that, in most cases, detailed risk assessment is unlikely to occur, especially since invasive species ecology is still in its infancy. Nevertheless, in principle, it is possible to estimate the area that is climatically receptive to pest species, with the usual caveats on genetic homogeneity, biotic interactions at both the source and destinations, and human-modified microhabitats, such as irrigated crops. This paper summarized the potential impact of climate change on crop pests and livestock disease for best management plans in Irrigated African Agroecosystems.

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1. Introduction

Insects, weeds and pathogen-mediated plant diseases are affected by climate and atmospheric constituents. Resultant changes in the geographic distribution of these crop pests and their vigor in current ranges will likely affect crops. Existing research has investigated climatic determinants of the range of many pests, but the potential changes in crop losses due to climatically driven changes in pests have not been included in most agricultural impact studies (Waggoner, 1983 and Stinner *et al.*, 1987).

Globally, the net effect of climate change has been predicted to increase pest damage to crops and trees (Karuppaiah. and Sujayanad. 2012). The introduction and distribution of alien insect pests are also likely to be driven by climate change as well as global trade. Conversely, such enhanced overwinterings would accelerate the spread of viruses by migrating vectors like aphids. Climate change will affect the distribution and degree of infestation of insect pests through both direct effects on the life cycle of insects and indirectly through climatic effects on hosts, predators, competitors, and insect pathogens. There is some evidence that the risk of crop loss will increase due to pole ward expansion of insect ranges. Climate change is likely to involve a higher frequency of abiotic disturbance. Depending on the dimension of

the disturbance, local to regional dynamics of insect populations and species composition will be strongly affected insects find optimum conditions for development within a certain range of temperature limited by species specific lower and upper developmental thresholds. These alteration and gradual changes might impact affect the population dynamics parameters like and c development and reproduction, diapauses and winter mortality and flight and dispersal (Warren *et al.*, 2001).

Climate change will also cause new patterns of pests and diseases to emerge, affecting plants and human health. In addition, increased incidence of water-borne diseases in wood-prone areas, changes in vectors for climate responsive pests and diseases, and the emergence of new diseases could affect both the food chain and people's physiological capacity to obtain the necessary nutrients from the foods they consume (Debay, 2010).

Climate change could also affect the distribution of vector-borne livestock diseases. These changes occur as a result of shifts in the geographical ranges of ticks, mosquitos, flies and other vectors. Diseases affected by these changes include East Coast fever, babesiosis, anaplasmosis and trypanosomiasis (CCAFS 2012).

In current production areas, the likely challenge of pests and diseases will mean that an increased focus on integrated management systems, especially host plant resistance and biological control, is essential. Pests and disease that were once minor problems can turn into major constraints and change their range of distribution with climate change. For example, projections illustrate these effects for three major cassava pests: the mealybug, the cassava green mite and the whitefly (**Herrera et al. 2011**).

Environmental conditions have a major influence on the survival, propagation and dispersal of plant pathogens. The effects of the climate are perhaps most obvious for fungal pathogens, which require suitable temperatures and minimum amounts of moisture to survive and reproduce and to initiate the infection process in plants. Most pathogens complete part of this life cycle on their host plants and the remaining part in the soil or on plant residues in the soil. Thus, temperature and moisture conditions in both air and soil are important for pathogen survival and development (**Chancellor and Kubiriba, 2006**). Climate is a prime determinant of the geographical distribution of plants, and climate variables have a major effect on the development of plant disease. Anthropogenic climate change will impact directly on crops and natural vegetation as well as on their interaction with plant pathogens (**Rosenzweig et al., 2000**).

Little research has been conducted into the effects of climatic change on plant diseases compared to studies on human, and to a somewhat lesser extent. Livestock diseases (**Coakley et al., 1999**). **Anderson et al., (2004)** suggests that severe weather events are making an important contribution to the emergence of plant diseases in new locations. There is an important interaction here, with the introduction of alien plant pathogens through trade in live plants, seeds and plant products. Climate change can potentially change physiology, morphology and the geographical distribution of crop and pasture species. How quickly a pathogen migrates to follow host plants will depend on a number of factors including its mechanisms of dispersal and its ability to survive on sources other than its primary host. Many plant pathogens with short generation time, high reproductive rate and effective dispersal are likely to respond rapidly to climate change. Opportunities to minimize potential loss from plant diseases can only arise from an improved understanding of the potential impact of climate change on plant diseases (**Chakraborty et al., 2002**).

2. Impacts of climate change on plant pests, diseases and weeds

It is generally concluded from recent scientific research that the severity of some pests and diseases

affecting crops of strategic importance have increased in the last few decades, and that this increase in severity can mainly be attributed to both climatic and socioeconomic factors. There is also clear evidence that climate change is generally altering the distribution and potential distribution, incidence and intensity of plant pests and diseases (**Herrera et al. 2011**).

The report of Fahim 2010 was expected to contribute to the potential impacts of climate change on agricultural pests and diseases is concerned, the study - in line with the results of the vulnerability assessment presented in the SNC and the NSACC - in a first step elaborates on the general relationships between climate change as evidenced by higher temperatures, changing humidity regimes, higher variability as well as an increase in extreme weather events (including spells of very high temperatures and droughts) and how these might affect the incidence of insects and plant diseases

2.1 Climate change impacts on plant diseases

Table 1 summarizes the disease epidemics under climate change during outgoing decades. Severe epidemics of potato and tomato late blight (*Phytophthora infestans*) emerged in the last few years. In practice (Fig 1), an epidemic onset is expected to lead to 2-4 additional sprays to be applied at the coming decades of the 2025-2100's (**Fahim et al., 2007 and Fahim et al., 2010**). Furthermore, it is a challenge for potato late-blight researchers in the future to find a balance between reduction use of pesticides usage and the pressure to increase pesticide utilization due to changes in climate and challenging the pathogen populations. Earlier onset of warm temperatures could result in the increase of a threat from late blight with the potential for more severe epidemics and increases in the number of fungicide applications needed for control. The results suggested that, the potential yield gain was almost completely offset when late blight was considered, chiefly because late blight outbreaks occurred from 4 to 7 days earlier (**Fahim et al., 2007**). Fig 1 showed estimated Potato Late Blight Risk for current potato production regions of the periods 1961-1990 in compared with the periods of 2040-2060, which will be increased by 10-15% (**Hijmans 2000 and Garrett and Cox, 2006**). Another study indicated that, the severities of current cultivars of wheat to leaf rust caused by *Puccinia triticina* and stripe rust disease caused by *Puccinia striiformis* increase with increasing temperature, which is projected under climate change conditions (**Abolmaaty 2006**).

The classic disease triangle recognizes the role of physical environmental in plant disease as no virulent pathogen can induce disease on a highly susceptible host if weather can induce disease on a highly susceptible host if weather conditions are not

favorable. Weather influences all stages of host and pathogen life cycles as well as the development of disease. Relationship between weather and disease are routinely used for forecasting and managing epidemics. And disease severity over a number of years can fluctuate according to climatic variation (Coakley, 1979; Scherm and Yang, 1995).

Environmental condition is complex term that includes many factors, which must be behind a minimum threshold for disease to occur. To study the interrelationship of the independent variable (Biological and meteorological) with disease development, the independent variable must be limiting or fluctuating between minimum and maximum conditions necessary for disease development. A change in one environmental factor may alter the effect of other environmental factors on disease development Abdel-HaK *et al.* (1966).

Concentrations of 3-7.5% CO₂ had no visible harmful effects on uredospore germination and early development of germ tubes of the rust fungi tested Manning and Andreas (1995); Coakley *et al.*, (1999) most analyses concur that in a changing climate pests may become even more active than they are currently, thus posing the threat of greater economic losses to farmers.

Data from the U.S. Department of Agriculture (USDA) show a 10-fold increase in both the amount and toxicity of insecticide use in the U.S. from the early 1940s to the 1990s, crop losses from pests rose from 30 to 37 percent, losses from insects increased from 6 to 13 percent, and losses to plant pathogens rose from 10 to 12 percent. Losses from weeds decreased from about 14 per cent to 12 percent Pimentel, 1995; IFPRI, (1998); Bagnall, (1988, 1991) there have been several attempts to establish correlations between time-series of historic pest damage and climate conditions. Among the earliest attempts to relate historic records of meteorological conditions and crop pest damage were the studies of potato leaf roll outbreaks in North America and Europe.

Yang and Scherm (1997) Study of the linkage between meteorological variables and pests is the wheat stem rust disease in the U.S. Great Plains. The epidemics of the disease from 1921 to 1962 seem to be related to the conditions during El Niño episodes. In contrast, wheat stripe rust epidemics in U.S. Northwest may be more severe during La Niña years Scherm and Yang (1995); Smith (1954) studied a 100-year record of grasshopper behavior as a pest in Kansas (1854-1954), showing that the most severe damage was caused during dry years. Chakraborty *et al.*, (2000) studied effect of climate change and potential impact on plant disease. Goudriaan and Zadoks (1995) investigated on global climate change:

modelling the potential responses of Agro-ecosystems with special reference to crop protection. Yang *et al.*, (2003) studied of predicting epidemics of yellow rust (*Puccinia striiformis*) on the upper canopy of wheat from diseases observations on lower leaves.

The distribution, incidence and severity of plant diseases are influenced by many interacting factors including host susceptibility, cropping systems, management strategies and environmental conditions. Climate is a prime determinant of the geographical distribution of plants, and climatic variables have a major effect on the development of plant diseases. Anthropogenic climate change will impact directly on crops and natural vegetation as well as on their interactions with plant pathogens Rosenzweig *et al.*, (2000); Agrios (1997) whereas free mycelium has to be in contact with moist surfaces to survive, most types of fungal spore can endure greater extremes of temperature and a wider range of moisture conditions. However, spores do need favorable moisture and temperature to germinate and, in the case of zoospores, free water is needed for their development and movement. For some diseases, the 'quality' of rainfall is a more important determinant of disease progress than the amount which falls. Septoria leaf blotches of cereals, for example, are spread through rain-splash – a process greatly enhanced during periods of heavy rainfall. Agrios (1997) the effect of temperature on disease development in plants is highly dependent on the specific combination of pathogen and host. Plants and pathogens each have optimum temperatures for growth and the degree to which they overlap varies among pathosystems. Describes the effects of the root rot-causing fungus, *Giberella zeae*, on wheat and maize. Knott (1989) on wheat, which grows best at lower temperatures than corn, disease develops most rapidly at temperatures above the optima for both wheat and the pathogen. On maize, however, the situation is reversed with maximum disease development occurring at temperatures below the optima for the crop and the pathogen. This suggests that the pathogen has an advantage over the crop under temperature conditions which are unfavorable to both. Thus, in some pathosystems at least, climate change-induced stress on plants may create enhanced opportunities for disease development. Further research is needed to investigate the mechanisms responsible for these effects. Climate interacts with other factors to impact on plant diseases. Climate and host resistance can affect the prevalence of races of fungal pathogens within geographical areas. Annual variation in populations of yellow rust of wheat, caused by the pathogen *Puccinia recondita tritici*, depend on climate and the resistance characteristics of the host varieties.

Temperature rises have been shown to affect the physiology of host plants and alter their resistance to disease. In another cereal crop, oats, experiments show that temperature-sensitive resistance to stem rust in varieties with the Pg3 and Pg4 genes is inactivated when temperatures rise above 20°C. Therefore, crop yield projections under future climate change scenarios need to take account of these potential affects. **Martens *et al.*, (1967); Cammell and Knight (1992)** indirect effects of climate may also be important. In particular, vector-borne diseases are strongly influenced by climatic effects on the vectors. There are established climatic thresholds for the phenological development of many arthropod vectors of plant viruses. Climate affects the fecundity and mortality of arthropod vectors and influences the number of generations in a year. In temperate climates, warm and dry conditions in early spring allow aphids such as *Myzus Persicae* to multiply rapidly and initiate damaging outbreaks of virus

disease epidemics. **Hulme *et al.*, (2001); Houghton *et al.*, (2001)** the size and geographical diversity of sub-Saharan Africa make climate change predictions particularly challenging. However, most of the current climate models² indicate that the overall scenario is one of rising temperatures and changes in rainfall patterns, with more prolonged and frequent drought and flooding. Mean temperatures over land areas are expected to increase by an average of around 1-2°C by 2020, with the largest increases occurring in southern Africa. By 2080, mean temperatures are expected to increase by c.1.7-6°C in southern Africa, 1.3-4.5°C in eastern Africa and 1.7-5.5°C in western Africa. There is less agreement between the various climate models for rainfall than for temperature. However, most predict a decrease in rainfall for southern Africa of approximately 5% by 2020 and 10% by 2050. Similar decreases are also anticipated in parts of the Horn of Africa, with some areas in eastern Africa likely to receive a significant increase in rainfall.

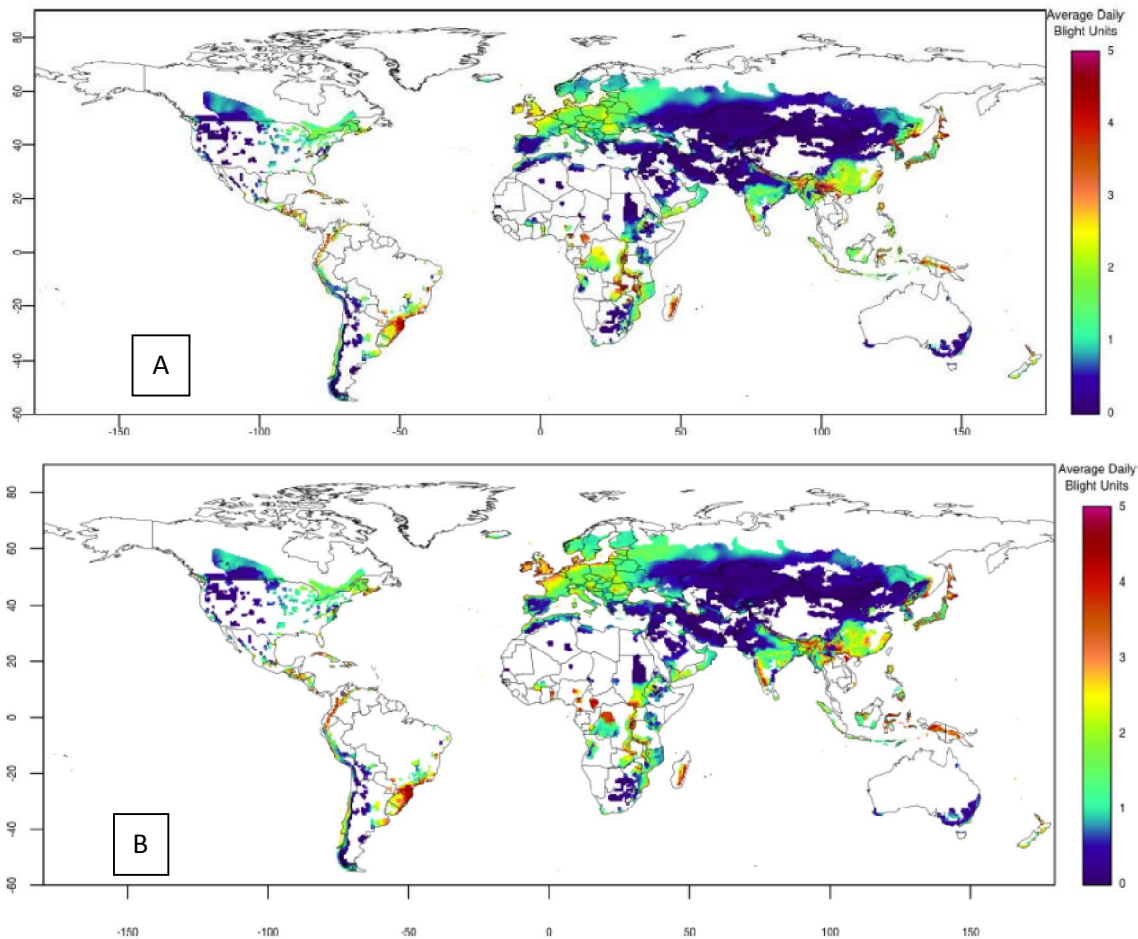


Fig 1: Estimated Potato Late Blight Risk for (A) current potato production regions of the periods 1961-1990 in compared with (B) the periods of 2040-2060 (Hijmans *et al* 2000 and Garrett and Cob, 2006).

Table 1: Summarized the mild disease epidemics under climate change during outgoing decades in Africa.

Diseases	Situation under climate change	References
Potato late blight (<i>Phytophthora infestans</i>)	In practice, an epidemic onset is expected to lead to 2-4 additional sprays to be applied at the coming decades of the 2025-2100's	Fahim et al., 2007 and 2010
	Estimated late blight for current potato production regions increased by 10-15% of the periods 2040-2060 in compared with the periods of 1961-1990.	Hijmans et al. 2000, and Garrett and Cox. 2006
Wheat leaf rust (<i>Puccinia triticina</i>)	There was not developed for severity of leaf rust disease during seasons of 2050 compared with seasons of 2006.	Abolmaaty et al., 2006
Wheat stripe rust (<i>Puccinia striiformis</i>)	Severity of strip rust disease was predicted to decrease during seasons of 2050 compared with seasons of 2006.	

2.2 Climate change impacts on plant insect pests

Insect life cycle processes affected by climate and weather include lifespan duration, fecundity, diapause, dispersal, mortality, and genetic adaptation. **Porter et al. (1991)** list the following effects of temperature on insects: limiting geographical ranges; over-wintering; population growth rates; number of generations per annum; length of growing season; crop-pest synchronization; interspecific interactions; dispersal and migration; and availability of host plants and refuge. Many effects involve changes in the severity of outbreaks following extreme weather events (on the order of hours to weeks). Temperatures that exceed critical thresholds frequently have adverse effects on fecundity, as in the cases

Some studies found (Table 2) that, generation numbers of *T. absoluta* under climate change conditions increased especially in Qena governorates (south Egypt). However, the expected generation numbers of the pest at 2050 and 2100 are be 12-14 and 13-15 generations per year, respectively (**Abolmaaty et al., 2010**). The similar results revealed to cotton pink bollworm *Pectinophora gossypiella* (**Yones et al., 2012**). Other studies revealed that, the insect generation period will be shorter under climate change

conditions in Egypt. For example, peach fruit flies (*Bactrocera zonata*) and potato tubeworm, the generation number will increase during the growing seasons (**Abolmaaty et al., 2011 and Khalil et al., 2010**).

Among the climatic factors, temperature is an important factor. The studies showed that, declined survival rate of brown plant hopper *Nilaparvatha lugens* (Stal) and rice leaf folder, *Cnaphalocrocis medinalis* (Guen) at higher temperature indicates the impacts of rising temperature could do the changes in the pest population dynamics of rice ecosystem. The alteration in the voltinism also could be the results of warming and it is more profit to multivoltine species and voltinism could be reflected in changes in the geographical distribution. Beside these, elevated CO₂ also showed some impact on pest's population abundance, the crop grown under the elevated CO₂ could alter the nutritional value of plants; it may alter the insect abundance and increase the consumption rate of herbivores. Therefore climate change would result in changes in the population dynamics of insect pests. Thus temperature rise plays a pivotal role in insect population dynamics (**Karuppaiah and Sujayanad, 2012**).

Table 2: Summarized the crop pest outbreaks under climate change during outgoing decades in Africa.

Insect pests	Situation under climate change	References
Tomato leaf miner (<i>Tuta absoluta</i>)	Expected generation numbers of the pest at 2050 and 2100 are be 12-14 and 13-15 generations per year, respectively.	Abolmaaty et al., 2011
Cotton pink bollworm (<i>Pectinophora gossypiella</i>)	Generation period will be shorter than nowadays by 25% during 2050	Yones et al., 2012
Peach fruit fly (<i>Bactrocera zonata</i>)	Increasing by one generation during 2050 and two generation during 2100	Khalil et al., 2010
Potato Tuber moth (<i>Phthorimaea operculella</i>)	Generation numbers of the tuber worm in 2050 and 2100 are expected to be 9-11 and 10-12 generations per year, respectively	Abolmaaty et al., 2011
Brown plant hopper (<i>Nilaparvatha lugens</i>)	The studies showed that, declined survival rate of brown plant hopper and rice leaf folder at higher temperature	Karuppaiah and Sujayanad, 2012
Rice leaf folder (<i>Cnaphalocrocis medinalis</i>)		

2.3 Climate change and possible impact on termite distribution in Africa

Potential impacts of climate change on pests such as termites are yet to be established. However, in recent times, there are few studies that have attempted to identify and establish the link between termites' distribution, invasions and climate; and how this distribution might change with global warming and changes in drought frequency (Ahmed *et al.*, 2006).

Farmers in Uganda and Zambia mentioned that termite problems are more serious now than in the past (Sekamatta and Okwakol 2007; Sileshi *et al.*, 2009). Damage by termites is greater during dry periods or droughts than periods of regular rainfall (Logan *et al.*, 1990). The increases in termite damage could also be associated with climate change induced drought. In recent decades, drought linked to El Niño episodes has become more intense and widespread in southern Africa (Harrington *et al.*, 2001).

A large number of alien invasive termites have established themselves in Africa. The direct and indirect effects from climate change will alter key demographic attributes, thus resulting in unanticipated population level consequences. There have been some rather spectacular documented cases of how climate can influence insect populations (Crozier, 2002). These include latitudinal and high-elevation expansion of butterfly and fruit fly distributions in Europe, shifts in life-histories, changes in plant defence chemistry affecting insects. In Africa, responses by pest insect populations to anticipated environmental shifts in the course of global climate change are largely unknown. An increase in temperature could result in an extension of ranges of some termites, with some being able to establish themselves in areas where they were previously unable to survive.

2.4 Climate change impacts on weeds

Weeds will benefit from the "CO₂ fertilization effect" and from improvements in water use efficiency associated with increasing CO₂ concentrations, but the impact on crop production will depend on how enhanced-growth weeds compete with enhanced-growth crops. Of the 86 plant species that contribute 90% of per capita food supplies worldwide, 80 are C3 plants (Prescott-Allen and Prescott-Allen, 1990), while 14 of the world's 18 worst weeds are C4 plants (Holm *et al.*, 1977). Experiments generally show C3 species to benefit from CO₂ enrichment at the expense of C4 species (Bazzaz and Garbutt, 1988).

Regarding temperature, most weeds of warm season crops originate in tropical or warm temperate areas and are responsive to small increases in temperature. For example, the growth of three leguminous weeds increased significantly as day/night temperature increased (Flint *et al.*, 1984).

Biomass of C4 smooth pigweed (*Amaranthus hybridus*) increased by 240% for an approximate 3°C temperature increase; C4 grasses also showed large increases (Patterson, 1993).

3. Impacts of climate change on animal transboundary pests and diseases

Depend on FAO 2008 report indicated that, some of the most dramatic effects of climate change on animal pests and diseases are likely to be seen among arthropod insects, like mosquitoes, midges, ticks, fleas and sandflies, and the viruses they carry. With changes in temperatures and humidity levels, the populations of these insects may expand their geographic range, and expose animals and humans to diseases to which they have no natural immunity.

Other climate changes can create more opportunities for vector-borne diseases. In pastoral areas, for instance, drier conditions may mean fewer watering holes, which will increase the interaction between domesticated livestock and wildlife. Increased interaction between cattle and wildebeest in East Africa could lead to a serious outbreak of malignant catarrhal fever, a highly fatal disease for cattle, since all wildebeest carry the fever virus. Aquatic animals are also vulnerable to emerging climate-related diseases, particularly since their ecosystems are so fragile and water is such an effective disease carrier. A fungal disease called the epizootic ulcerative syndrome recently expanded to infect fish in southern Africa due in large part to increases in temperature and rainfall levels.

Pests and diseases have historically affected food production either directly through losses in food crops and animal production, or indirectly through lost profits from insufficient cash crop yields. In the current time, these losses are being exacerbated by the changing climate and its increasing volatility, threatening food security and rural livelihoods across the globe.

Developing countries with a high reliance on agriculture are the most vulnerable to today's changing patterns of pests and disease. Hundreds of millions of smallholder farmers depend solely on agriculture and aquaculture for their survival. As rural farmers struggle to produce food, poor people in nearby urban areas are left to contend with less availability in addition to higher food prices. National economies will also suffer as new pests and diseases either reduce agricultural products' access to international markets or incur higher costs associated with inspection, treatment and compliance.

Biological control of weeds and other pests depends on the synchrony between the growth, development, and reproduction of biocontrol agents and their targets. Such synchrony may be disrupted if

climate changes rapidly, particularly if climatic extremes occur more frequently. Global warming could facilitate overwintering of insect populations and favor earlier poleward migrations in the spring, which could increase the effectiveness of biological control of weeds in some cases.

4. Climate change impacts on pesticides demands

Some new elements of assessment, particularly as regards the potential negative impacts of increased pesticide use. The increasing incidence of diseases and pests will not only result in higher costs related to inspection, treatment and compliance with the obligations of the importing trading partners, but trade disputes under WTO might also become more frequent and more costly to resolve. Investments in early control and detection mechanisms will undoubtedly be valuable, in order to avoid higher costs of eradication and control. Adaptation to the increased potential of spread of plant pests and diseases under different climate scenarios requires higher levels of forecasting, prevention, early warning and early reaction. Early detection and identification, including through genotypic characterization, preparedness for and rapid response to new and emerging pests are further critical elements (**Karuppaiah and Sujayanad. 2012**).

Increasing CO₂ and climate change probably will also affect mechanical, chemical, and natural/biological efforts to control weeds (**Patterson, 1993**), which currently cause worldwide crop production losses of about 12% (25% for traditional production systems) (**Parker and Fryer, 1975**). Environmental factors including temperature, precipitation, wind, soil moisture, and atmospheric humidity influence when herbicides are applied, as well as their uptake and metabolism by crops and target weeds. High leaf starch concentrations, which commonly occur in C3 plants grown under CO₂ enrichment, might interfere with herbicide activity. CO₂ enrichment also increases the growth of rhizomes and tubers in C3 plants (**Oechel and Strain, 1985**), which could reduce the effectiveness of chemical and mechanical control of deep rooting, perennial C3 weeds. On the other hand, increased temperatures and increased metabolic activity tend to increase uptake, translocation, and effectiveness of many herbicides.

5. Strengthening cooperation and early detection

FAO 2008 reported that, global cooperation therefore is required to respond to it. However, given the nature of plant pests and animal diseases, more localized or regionalized strategies will be needed to be effective. Investments in early control and

detection systems, including border inspections, will be a key to avoid the higher costs of eradication and management. Coordinated research, including programmes related to climate change and food security from the Consultative Group on International Agricultural Research, will be needed to improve the range of options available to countries.

International trade and traffic spread transboundary animal and plant pests and diseases and alien invasive aquatic species. Countries take measures to keep new diseases and pests out. Such measures may hinder the free flow of goods and should therefore be scientifically justified and be as limited as possible in their effects on trade. New uncertainties and possibilities of introduction caused by climate change have the potential to increase these regulations and their effect on trade.

The containment of some pests and diseases may not be feasible because, for example, they are spreading too fast. New farming practices, different crops and animal breeds, and integrated pest management principles must be developed to help stem their spread.

Governments may need to consider the introduction of biological control agents or new pest- or disease resistant crops and breeds. Governments need to strengthen national animal and plant health services as a top priority. They need to focus on basic sciences, such as taxonomy, modeling, population ecology and epidemiology. Governments should also consider how to better consolidate and organize their national animal and plant health services since they are often fragmented across different ministries and agencies.

6. Recommendations for climate change adaptation planning for agricultural pests in Africa

Designing and applying of national/regional adaptation strategy for the agriculture sector is facing a group of barriers and limitations of existing scientific, information and policy perceptions, poor adaptive capacity of the rural community, lack to financial support, and absence of the appropriate institutional framework. For adaptation action plans for Africa should be the following:

- Improvement of crop/livestock programs with the objective of developing a map for the observation of diseases and their causes, their prevalence in different agricultural environments and major crops as a result of changes in climate indicators, and assisting plant breeding programs in developing priorities on how to combat pathogens, and how to neutralize their impact on the efficiency of production.
- Strengthening plant protection programs to follow

up on the changes in the biological diversity (species and varieties) of insects, and its association with trends in the relevant climate change indicators. Identifying how to maintain a positive balance which benefits agricultural production in different environments.

On the other hand, it clearly reveals that so far very little is known about the potential, climate change induced impacts of increasing pest and disease problems on agricultural production at the national level and the resulting importance in both macro-economic and socio-economic terms. Accordingly, the study could not quantify the costs (in both financial and economic terms) of climate change induced increases of agricultural pests and diseases and their production and productivity effects, nor could the costs of possible adaptation measures be estimated.

Finally, it is suggested that for complementing the vulnerability assessments done so far in the area of agricultural pests and diseases, the potential impacts of deteriorating irrigation water quality and the projected increase in the reuse of treated waste water on the incidence of pests and diseases should also be systematically taken into account.

7. Conclusion

In recent years part of the debate on climate change and agriculture focused on how farmers will adapt to climate change. This included the need to shift varieties and crops and to develop models that will tell which varieties will be adapted to future climate. The same can be said for pests and diseases. Pest distribution will change as a result of climate change and disease epidemics can shift. Disease epidemics are strongly linked to climatic conditions and therefore some diseases may disappear or lose their predominance in a given production system and new pathogens or new strains can become more important. It is therefore necessary to deploy in the production system with the diversity needed not only to adapt to the new climatic conditions but also to the new pathogens that might arise as a result of shifting climates. While it can be tried to predict new climatic conditions and therefore future abiotic constraints and look for varieties that are adapted to the new conditions, it is more difficult to do so for pests and diseases, exactly because they are living organisms and therefore can always mutate. We cannot be sure that the strains and their pathogenicity will remain the same in a different environment and therefore we cannot really be sure that the varieties will be resistant in the future scenario.

The general autonomous and planned adaptation measures listed in the IPCC Fourth Assessment Report should be considered when

formulating local, national and regional strategies for adaptation to plant pests and diseases under climate change scenarios. Additional information and research is required on the distribution of plant/animal pests and diseases, and on their epidemiology. In particular, there is a need for better surveillance methodologies; epidemiological knowledge; and information on biological control organisms and mechanisms; resistant crops breeds and species. Better accessibility and analysis of existing historical data and more detailed data for all regions in relation to different climate change scenarios would contribute to improving the baseline studies needed to identify and assess adequate adaptation measures.

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